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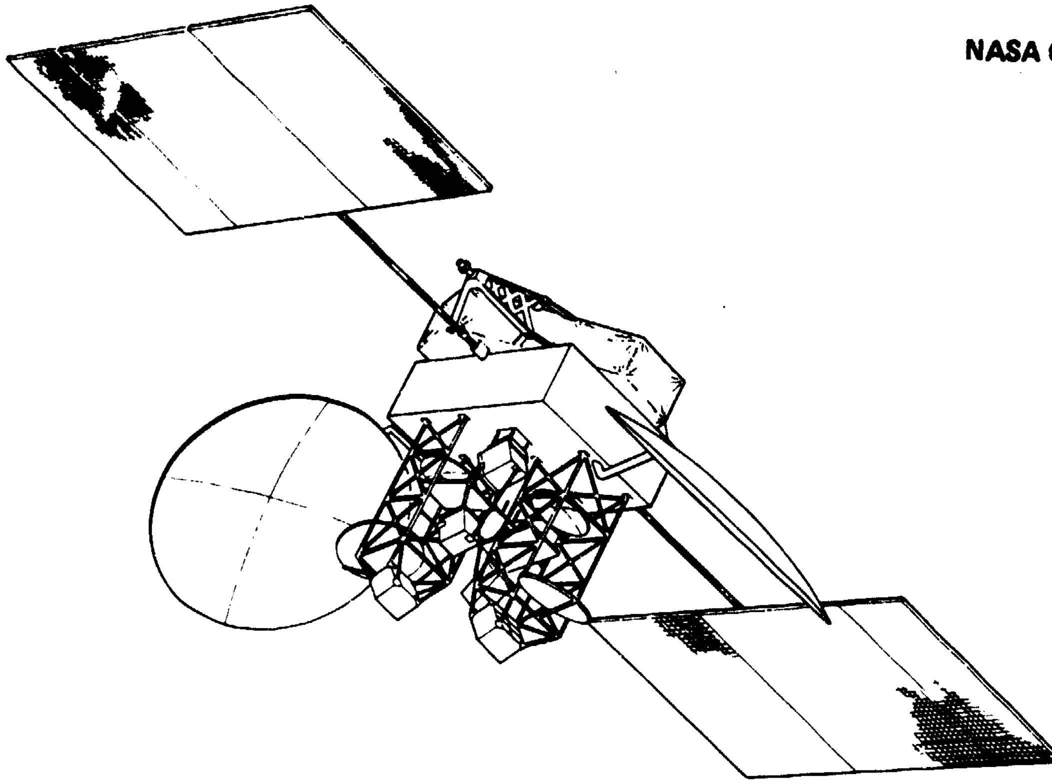

30/20 GHz MIXED USER ARCHITECTURE DEVELOPMENT STUDY

EXECUTIVE SUMMARY

TRW Inc., Space Systems Division

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center

Contract NAS 3- 21933

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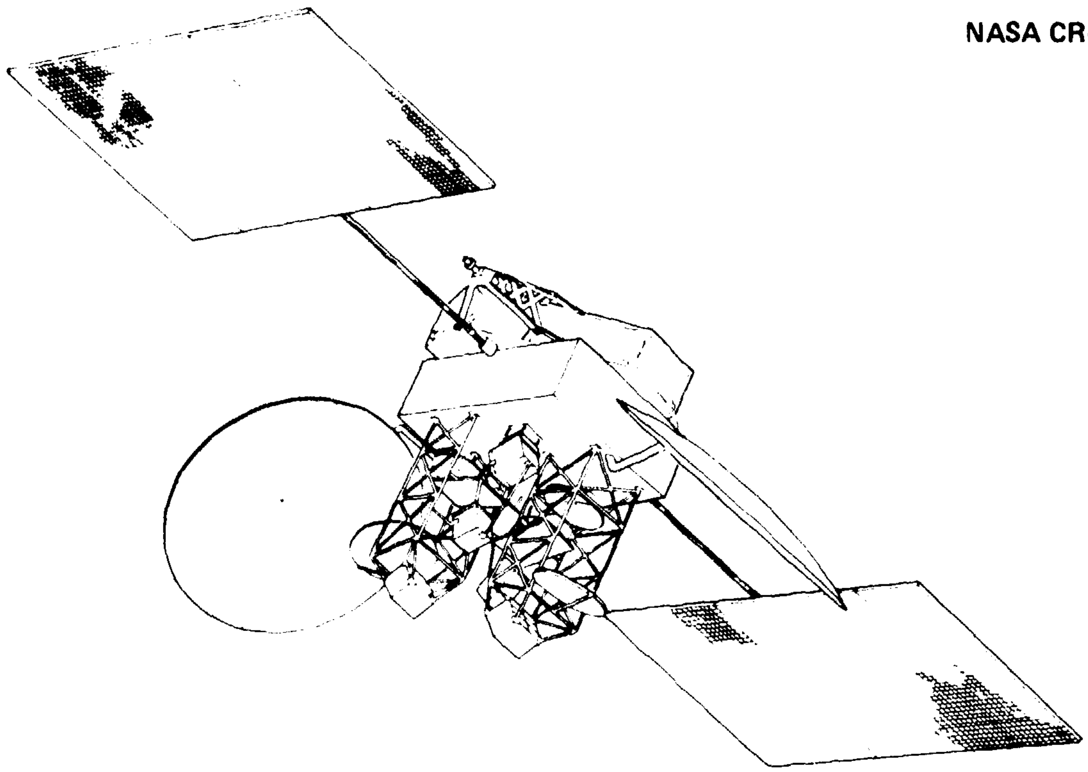

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16. Abstract

A mixed-user system is described which provides cost-effective communications services to a wide range of user terminal classes, ranging from one or two voice channel support in a direct-to-user mode, to multiple 500 mbps trunking channel support. Advanced satellite capabilities are utilized to minimize the cost of small terminals. In a system with thousands of small terminals, this approach results in minimum system cost.

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EXECUTIVE SUMMARY

The 30/20 GHz Mixed User Architecture study has resulted in a baseline system design for cost-effective communications in the years 1990 to 2000. Generation of a useful mixed user TDMA architecture has required a broad overview of system characteristics. The 30/20 GHz baseline system consists of a synchronous orbit satellite, 18 large trunking terminals with 12-meter apertures and 10-km space diversity, 25 to 30 small, trunking terminals with 6-meter apertures and 10-km space diversity, several thousand inexpensive direct-to-user (DTU) terminals, and a master control station with at least one alternate master control station.

The DTU terminal minimum-cost design offers the greatest challenge in the 30/20 GHz communication system. Since the number of DTU terminals is very large, the DTU terminal cost is a large (perhaps the largest) element of system cost. The DTU terminal performance drives the satellite design, and hence determines the cost of a second major system element. Because the DTU system is able to avoid using terrestrial signal distribution and routing, and the charges associated with these functions, the DTU system also represents the largest economic value element of the system.

Because of these factors, the 30/20 GHz TDMA Mixed User Architecture design starts with the definition of DTU user terminal characteristics. TDMA, control, and on-board processing architectures are selected to maximize system performance with minimal DTU terminal requirements.

Trunking terminal design and the satellite trunking support components are less critical elements in determining system cost effectiveness. Trunking at 30/20 GHz provides direct cost benefits and prevents saturation of the lower frequency satellite communication bands. The greatest economic benefit of integrating both systems results from the increased utility of the DTU terminals.

DTU terminals need to integrate their communications channels with a trunking system. A large percentage, perhaps greater than half, of DTU point-to-point communication channels will terminate or originate in a trunking area. By shifting signals from the DTU system to the trunking system in the satellite, the more expensive DTU system carries less total

traffic. Signal routing is greatly simplified. Without this interconnectivity it might be necessary to provide DTU terminals at each trunking location to provide integration and avoid double-hop routing.

The baseline 30/20 GHz satellite communication system resulting from this study incorporates on-board satellite demodulation and routing of individual 64 kbps, digital voice-grade circuits. This level of routing flexibility is necessary to provide efficient communications to the very large number of DTU terminals projected. From an external point of view, the resulting system looks very much like a very large, distributed, telephone switching system. The circuit interfacing hardware is distributed among all the DTU and trunking terminals. Control and routing computers are at master control stations. The switching circuitry which provides full interconnectivity between 30 to 45 thousand circuits is in the satellite.

The satellite (Figure 0-1) must be fairly large to provide such a capability. Table 0-1 describes the satellite characteristics required to support the baseline system.

A. Satellite Baseline Design

The baseline system design includes a single, large, synchronous-orbit satellite. Communications design features include:

- All antenna beams provided by two 3-meter apertures
- Complete coverage of the 48 contiguous states
- Fixed-beam coverage of 18 high-density areas
- Scanning-beam coverage of all other areas
- Antenna beamwidths of 0.3 to 0.5 degree
- Dual mode 75-/7.5-watt 20-GHz downlink fixed-beam TWT transmitters
- Fixed level 35-watt downlink scanning-beam TWT transmitters
- Total radiated 20 GHz RF power of about 500 watts

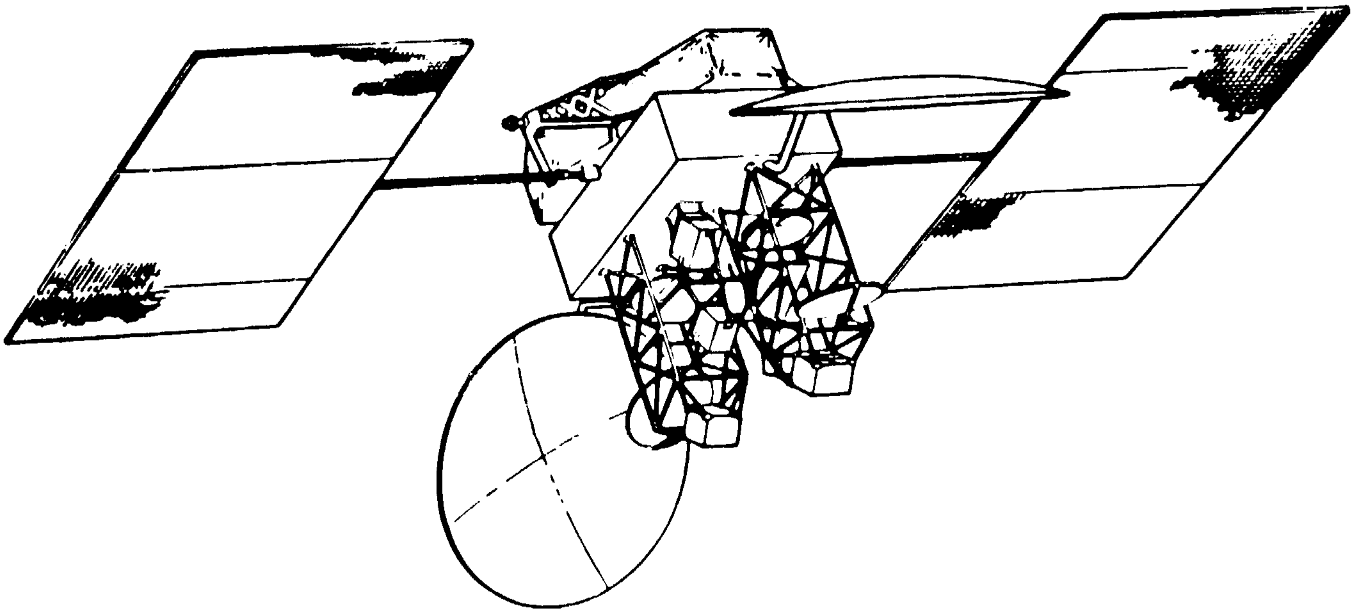

Figure 0-1. Preliminary Satellite Design

Table 0-1. Satellite Summary

• 6130 POUNDS BOL, 4360 WATTS INCLUDING ECLIPSE
• 10 YEAR STATIONKEEPING - WEIGHT IS 5160 POUNDS WITH ION PROPULSION
• 0.03 DEGREE POINTING ACCURACY RESULTS IN RF SENSING
• ABOUT 36 TWTA - 7.5/75 WATT DUAL MODE - 24 ACTIVE
• ABOUT 100 DEMODULATORS - 25, 125, 500 MBPS - 60 ACTIVE
• 10 GBPS THROUGHPUT CAPACITY - 3 GBPS PROCESSOR THROUGHPUT
• PROCESSING INCLUDES INDIVIDUAL CHANNEL ROUTING, ADAPTIVE CODING

The satellite communication subsystem block diagram is shown in Figure 0-2. It consists of a 500 Mbps per channel, spacecraft-switched, time-division multiple-access (SSTDMA) support section for trunking station and an on-board digital data processing section for small user support of small trunking terminals and DTU terminals.

The satellite provides 500 Mbps TDMA burst-rate communication between 18 large trunking users with a SSTDMA high-capacity communications system. The high-rate uplink channels are sequentially connected to different high-rate downlink channels. The connection patterns, or modes, repeat over a 1-millisecond frame period. The modes and the dwell-time in each mode may be varied by command, but are usually stable for long periods of time (hours). This interconnectivity technique allows all large trunking users communications access to all other large trunking users with an access period appropriate for the amount of data to be communicated. The large trunking user locations supported by the baseline system are shown in Figure 0-3.

The SSTDMA frame time line for the fixed-beam channels (Figure 0-4) illustrates the 500 Mbps channels being used first for communications between trunking stations and then for DTU terminal communications. Only six trunking time lines are shown for clarity, and only one of these is broken down to show DTU utilization. The Chicago uplink beam is shown being connected sequentially to New York, Los Angeles, Atlanta, and other major trunking locations. Similar sequential interconnection patterns are used on the other uplink channels.

After the Chicago trunking terminal has transmitted all outgoing traffic, the 500 Mbps channel is available for use by DTU terminals. Since they do not operate at 500 Mbps, the channel may be FDM divided to provide four 125 Mbps channels. One of these is shown to be further divided into 25 Mbps channels (31.25 MHz) to allow communication by very small DTU terminals. All DTU communications pass through the on-board processor.

Uplink and downlink SSTDMA frames are similar, but generally not identical since traffic output from an area may be different than traffic into that area. Also, DTU data rates are different for uplinks and downlinks.

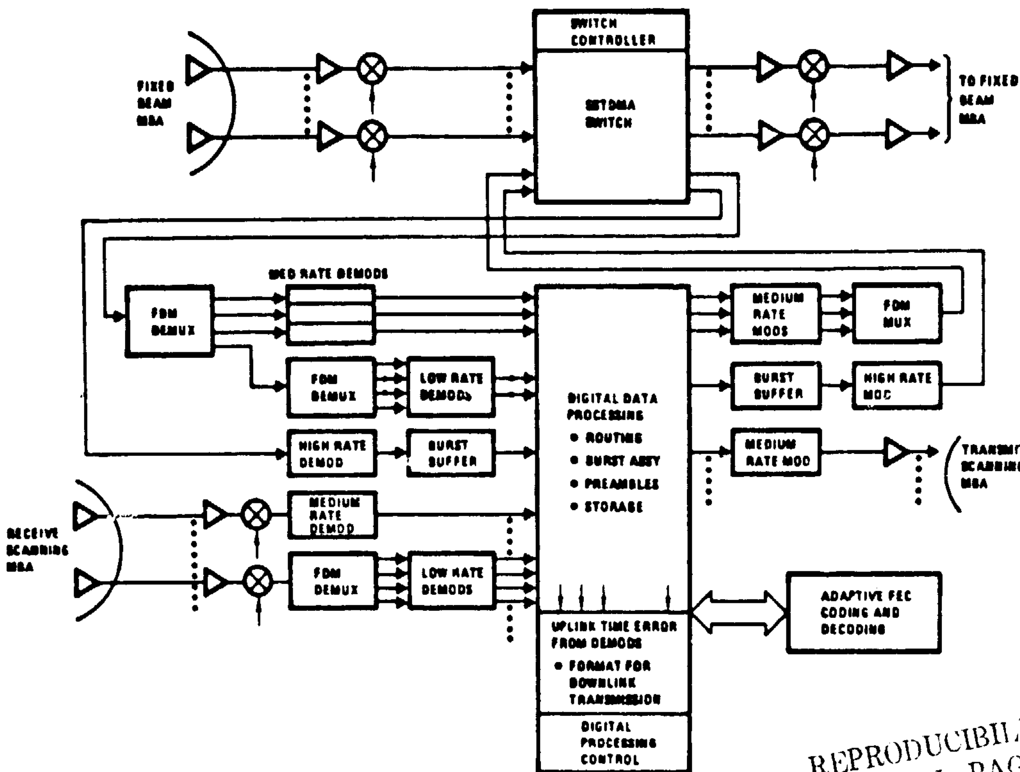

Figure 0-2. Satellite Communication Subsystem Block Diagram

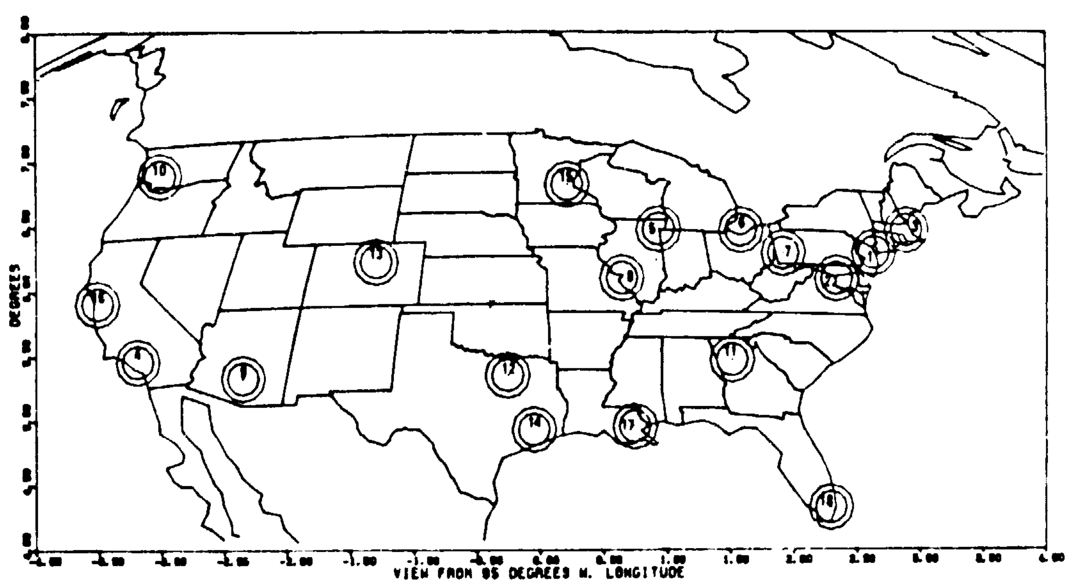

Figure 0-3. Trunking Station Plot

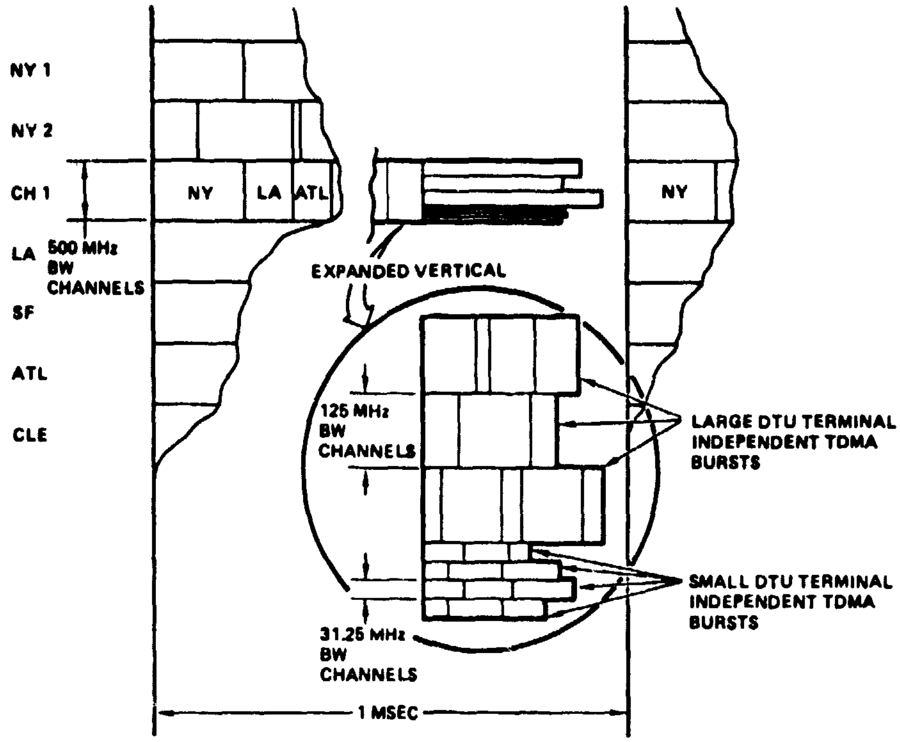

Figure 0-4. SSTDMA Frame Time Line, Fixed Beams

The satellite provides DTU communications between small terminals using 25 and 125 Mbps uplink burst rates and 250 Mbps downlink burst rates. DTU terminal average data rates vary from 64 kbps to as high as 100 Mbps. The satellite demodulates, routes, and remodulates the DTU signals and operates as a switchboard, providing the capability for one DTU terminal to talk to any combination of other DTU terminals. The satellite also provides adaptive forward error correction coding (FEC) on the uplink and downlink DTU signals to combat the effects of intense localized rain at a DTU terminal site.

There is no clear separation between DTU and trunking systems on the satellite. Those DTU terminals located in areas covered by the 18-beam, fixed-beam antenna system communicate through that antenna system in frequency-time slots not used by the high-capacity trunking terminals. Smaller trunking terminals located outside the fixed-beam areas communicate through the satellite on-board processing subsystem. Both small trunking terminals and DTU terminals communicate with large trunking terminals through buffers which interface a small portion of the 500 Mbps throughput with the on-board processor.

The entire satellite data rate capacity is about 10 Gbps. Of this, 8 Gbps is trunking and 2 Gbps is DTU traffic. About 8 Gbps of the traffic is located in the high-density areas served by the 18 beam fixed-beam antennae, and about 2 Gbps is in the scanning beam coverage area. Since all DTU traffic and all trunking in scanning-beam coverage areas must flow through the processor subsystem, the total on-board processor throughput is about 3 Gbps. About 1 Gbps of data must interface between the high capacity 500 Mbps SSTDMA and the on-board processing subsystems.

A portion of the 500 Mbps large trunking station data must be demodulated and remodulated to allow interfacing with the small trunking and DTU data. Because of the complexity of large SSTDMA IF switches, demodulation and remoduation of all high-rate data may be attractive. The complexity, size, weights, and power of demodulators may be small enough to reduce the overall system cost by this approach.

Because of the uncertainty of the development rate of the required technology, and because demodulation strips off timing information needed for system timing functions, the baseline satellite design uses IF switching SSTDMA at the 500 Mbps data rate. Complete demodulation and remodulation will be considered an option, subject to technology availability.

Spacecraft design requirements imposed by the communications mission, normal design practices, and assumed schedule are as follows:

- Ten-year design life, including 0.05- to 0.1-degree inclination control
- 0.03- to 0.05-degree antenna pointing
- Multimode 75-/7.5-watt fixed-beam transmission with ring redundancy
- Scanning beam redundancy by 50 to 60 percent transmitter operation
- Full eclipse operation
- No single-point failures for active components
- Shuttle launch
- 1985-1986 technology for a 1990 first-launch capability.

Based on these requirements a preliminary satellite design has been synthesized. The satellite is three-axis stabilized using reaction wheel control with RF sensing on the fixed-beam antennas providing two axes of sensing and either differential RF sensing or differential RF sensing and earth sensing providing the third axis. The antenna configuration consists of two 3-meter apertures, each with its associated tower housing feed networks and auxiliary reflectors. Each antenna system supplies nine of the 18 fixed spot beams, receive and transmit, as well as transmit and receive scanning beams. The antenna designs are similar to those synthesized in previous TRW in-house studies for advanced, high capacity communications satellites. The two 3-meter reflectors are stowed in approximately a north-south orientation and are deployed with a single hinge motion to assume their in-orbit east-west orientation.

The spacecraft is modular in design and includes an upper communications module plus a lower shuttle bus. The communications module houses the communications equipment, tracking telemetry and command RF equipment as well as earth and RF sensors. The communications module, shown as a box, can be augumented by north-south compartments extending alongside the antenna towers. These will house output elements such as TWTAs and output filters, providing additional thermal radiating area and shorter waveguide runs to the feeds.

The shuttle bus houses both the spacecraft service equipment as well as the apogee-perigee propulsion equipment for injection into geosynchronous orbit. The latter consists of a set of six tanks (three fuel and three oxidizer) in combination with low thrust bipropellant motor(s), one or two, which provide the roughly 4370 meter/sec total velocity increment required to move the satellite from the shuttle orbit to synchronous orbit. The tanks are arranged in balanced pairs (fuel and oxidizer) to maintain the configuration balance, and are jettisoned in pairs as they are depleted. TRW is in the process of performing in-house engineering on this flexible, low-acceleration approach for use on a number of geosynchronous and interplanetary missions. This approach provides considerable cost savings in both upper stage and shared Shuttle launch costs, compared with the IUS. The bipropellant engine(s) are gimbaled to provide control about the transverse axes. Control about the thrust axis is supplied by the hydrazine thrusters used for on-orbit attitude control.

Apogee is reached following a set of 10 to 12 perigee burns, each of 10 to 15 minutes duration. Perigee burns are programmer-controlled due to poor ground station visibility of the areas where perigee burns occur. Communication via TDRSS might be used to provide ground overide but capability is not required. Perigee burn accuracy is not critical. Up to 4-degree pointing errors can be tolerated during perigee burns. Three to four apogee burns are used to circularize the orbit. The truncated triangular shape provides a convenient trunnion shuttle interface, and allows ejection from the shuttle by springs.

Power requirements and weight estimates given in Tables 0-2 and 0-3 are dominated by communications requirements. The communications system estimates are based on extrapolations of equipment technology to the 1985-1986 era for RF LSI and for digital micro-electronics, both under development at TRW. Size, weight, and power estimates have been checked against previous estimates made at TRW for advanced high-data-rate communications satellites. The fixed-beam TWTAs are assumed to be two-level devices, 75 watts and 7.5 watts, which operate only infrequently in the high power mode. The amplifier efficiency is 35-percent in the high power mode and 25 percent in the low power mode. The high power mode is supplied from the spacecraft batteries. The scanning-beam TWTAs are single-level 35-watt amplifiers. Only 60 percent of the complement of 20 tubes are operating at any one time.

Secondary power conversion is within the communications subsystem. The power requirement estimate is based on distributed power converters within each unit, fed by an unregulated bus. The power estimate in Table 0-2 is valid for either ion propulsion or heated hydrazine thrusters (HiPeht) which normally are fired only during the 270 days of noneclipse season. Hence, the charge array is sized to provide charge power, load and trickle, throughout the year to recharge sequentially two sets of two 50-Ah, nickel hydrogen batteries. These batteries, with cell bypass redundancy, are sized to provide either full communications eclipse load or full ion propulsion load. (The HiPeht requirement is less stringent.)

Table 0-2. Average On-Orbit Power Requirements

		Watts
Communications		3215
Receivers	425	
Digital Processing and TDMA Switch	475	
Transmitters (Less TWTAs)	180	
Fixed Beam TWTAs (7.5 W at 25 percent)	540	
Scanning Beam TWTAs (35 W at 35 percent)	1200	
Scanning Beam Drive and Control	395	
Attitude Determination and Control		90
Tracking Telemetry and Command		50
Thermal Control		50
Electrical Power		10
Subtotal		3415
Distribution		75
		3490
Charge Array		460
Margin (10 percent)		400
Total		4350

Table 0-3. Spacecraft Weight Summary

	HiPeht		Ion Propulsion	
	(lb)	(kg)	(lb)	(kg)
Communications	1,406	638	1,406	638
Antennas	466	211	466	211
Electrical Power and Distribution	874	396	874	396
Attitude Determination and Control	202	92	202	92
Structure/Thermal	900	408	900	408
Hydrazine Reaction Control	185	84	46	21
Ion Propulsion	--	--	303	137
RF Sensor	12	5	12	5
Tracking Telemetry and Command	110	50	110	50
	4,155	1,884	4,319	1,958
Contingency (15 percent)	625	283	648	294
Pressurants and Residuals	4,780	2,167	4,967	2,252
Hydrazine Propellants, Pressurants and Residuals	1,350	613	60	27
Mercury Propellants, Pressurants and Residuals	--	--	137	62
Spacecraft at Beginning of Life	6,130	2,780	5,164	2,341
Shuttle Bus Propellants	27,300	12,380	23,000	10,430
Shuttle Bus Dry Weight	2,900	1,315	2,446	1,109
Spacecraft Weight at Shuttle Separation	36,330	16,475	30,610	13,880
Spacecraft Cradle/Ancillary Equipment	1,130	512	1,090	495
STS Installed Weight	3[illegible],460	16,987	31,700	14,375

The eclipse battery requirement can be made equivalent to the ion propulsion thruster requirement. For eclipse, the approximately 5000-Wh requirement includes two fixed-beam tubes on high power mode for 1 hour. This requires four 47-Ah batteries with 28 cells at an 80 percent depth of discharge. By contrast, two 9-millinewton ion thrusters are fired for 3.85 hours at each of two nodes requiring about 2650 Wh for each node. The requirement in this case is about 50-Ah. With a recharge rate of C/10 and recharge ratio of 1.2 (put back 1.2 times the energy used) 420 watts are required for about 8 hours to recharge the two batteries. Additional technology work on nickel hydrogen batteries is required to justify the 80 percent depth of discharge for the 2000 to 2500 cycles assumed, i.e., (10 years)(90 cycles) + (5-6 years)(270 cycles).

The solar array power of 4.4 kW can be obtained by a number of different solar array techniques. Recent studies by TRW for a NORDSAT Direct Broadcast Satellite investigated lightweight foldout such as the SEPS or PEP concept under investigation by Lockheed and TRW, the rollout array typified by DORA (AEG/Telefunken) or FRUSA (Hughes) or the lightweight rigid ULP (MBB). The particular configuration shown in Figures 0-1 and 0-2 lends itself to the lightweight rigid array of MBB, the heaviest of those studied. Assuming a cell output improvement to 80 watts/m^2 at 10-year solstice, roughly 15 percent better than TDRSS technology, a weight of 27 kg/kW (including yoke but without drive mechanisms) is estimated.

The spacecraft weight summary is shown on Table 0-3 for the two cases of on-orbit propulsion. For the case of heated hydrazine (HiPeht), only inclination control is provided by the HiPeht thrusters. Attitude control and east-west stationkeeping is provided by conventional hydrazine one pound thrusters. In the case of ion propulsion, the results are based on a study of mercury thrusters performed by TRW for NASA Lewis. The higher thrust 9-millinewton level is used rather than the 4.5-millinewton level studied, because of the heavier spacecraft. Conventional hydrazine thrusters are also carried for apogee/perigee control, initial acquisition and other attitude control functions, but north-south and east-west stationkeeping and momentum dumping are performed using the body mounted gimbaled ion thrusters.

The use of ion propulsion is dramatic in its weight saving (roughly 1000 pounds at beginning of life and almost 6000 pounds in STS installed weight). Since the use of Shuttle bus rather than IUS results in a relatively short STS installation, Shuttle launch charges are based on weight rather than length. The weight saving is equivalent to a $3.3M saving per launch in 1979 dollars using the shared launch formula for commercial launches (i.e. $18.4M compared with $21.7M).

The weight of the communication and antenna subsystems dominate the dry weight, as would be expected. For the fixed-beam units, a ring redundancy concept has been adopted with three sets of nine-for-six redundancy for the active units. Hence, a total of 27 TWTAs are provided for the 18 active beams. For the scanning beam, redundancy is achieved by the use of 50 to 60 percent of the available scan zones. The failure of equipment will necessitate reconfiguration of the scan zone geometry by ground switching. The demodulator technology is most difficult to estimate at this time. This may cause a large swing in the final weight since about 100 are being carried. For this weight estimate 1 kg is alloted to each unit.

The antenna reflector weight estimate is 0.5 lb/ft^2, similar to TDRSS and Intelsat V antennas. Advanced mesh reflectors could be lighter at the expense of greater cost and complexity.

Electrical power and distribution includes the solar array at 27 kg/kW (discussed earlier); four 50-Ah nickel hydrogen batteries at 1.3 kg/cell for 28 cells plus 15 percent packaging plus 3.7 kg/battery for cell bypass circuitry; a power control unit, a spacecraft converter and the power and signal harness. All RF cabling is estimated as part of the communications subsystem. Attitude determination and control is based on the aforementioned NORDSAT Study, on TDRSS/FLTSATCOM technology, and a three-axis control study (for Intelsat) on the use of four skewed reaction wheels. Tracking, telemetry and command assumes the use of S-band for preorbital operation and K-band for on-orbit operation. TDRSS technology and weights have been assumed. The adoption of advanced technology would undoubtedly lead to some weight saving but it would not be dramatic compared with the new communications technology savings or HiPeht versus ion propulsion savings.

Structure/thermal is estimated based on factors calculated for FLTSATCOM and TDRSS. Thermal control for the high power communications equipment would utilize heat pipe radiators especially because of the high and low power modes and the ring redundancy. If such a common baseplate approach were not used, each 7.5-/75-watt TWTA would have to be designed for its maximum heat dissipation. The increase in radiator weight would be a prohibitive factor of 10.

A contingency factor of 15 percent is typical for such a preliminary estimate. The weight at shuttle separation is roughly six times the weight of the spacecraft at beginning of life. This is based on a number of propulsion-sizing studies recently performed at TRW. The lightweight cradle design is also extrapolated from recent TRW studies.

B. DTU Terminals

There are two DTU terminal classes, both corresponding to nominal terminal apertures of 3 meters. Terminal requirements are summarized in Table 0-4. There may actually be a range of DTU terminal sizes and designs. Figure 0-5 is a generalized small terminal block diagram. Certain DTU terminal parameters are allowed to vary to match site and user requirements. These parameters include antenna size, transmitter power, preamplifier noise-figure, transmitter redundancy level, and receiver redundancy level. Other terminal components will be standardized, leaving the variable parameters to accommodate individual user and site requirements.

The smallest DTU terminal class uses a 25-Mbps uplink burst rate and a 10-watt transmitter. The downlink data rate is the standard 250-Mbps burst rate, but the clear-weather margin will be low and adaptive forward error correction coding (FEC) will be needed quite often to overcome rain losses. The satellite charges for service to this class of user should be relatively large, since a disproportionate share of satellite resources are required to provide communication service. Five times as many satellite demodulators are required to provide a given throughput as compared to the large DTU terminals.

Table 0-4. Terminal Summary

LARGE TRUNKING TERMINALS (18 REQUIRED)
12-M ANTENNAS
DUAL TERMINAL 10 KM SEPARATION DIVERSITY (0.9999 AVAILABILITY)
500 MBPS SSTDMA
LARGE DIRECT-TO-USER TERMINALS (SEVERAL THOUSAND)
3-M ANTENNAS, 50 WATT TRANSMITTERS
NO DIVERSITY (0.999 AVAILABILITY)
125 MBPS UP, 250 MBPS DOWN BURST RATE
INTERFACE BASED ON DS1 1.544 MBPS SIGNAL
INDIVIDUAL 64 KBPS CHANNEL ROUTING
SMALL TRUNKING TERMINAL (50 REQUIRED)
TWO LARGE DTU TERMINALS WITH 10 KM DIVERSITY
0.9999 AVAILABILITY
SMALL DTU TERMINAL (SEVERAL THOUSAND)
25 MBPS UP, 250 MBPS DOWN
3-M ANTENNA, 5-WATT TRANSMITTER

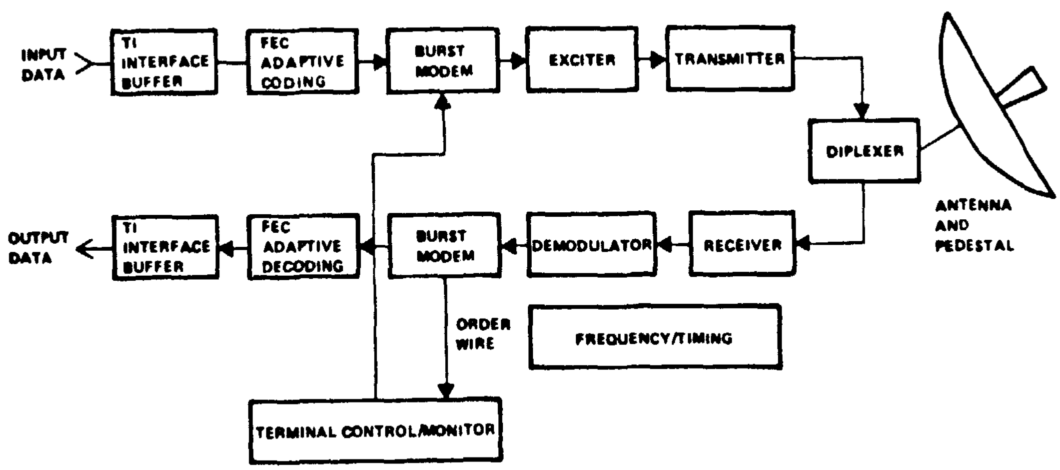

Figure 0-5. Small Earth Terminal Block Diagram

Larger DTU terminals use a 125-Mbps uplink burst rate and a 50-watt transmitter. Satellite charges should, therefore, be lower for these terminals on a per-circuit basis since less satellite hardware is required for their support. The terminal class must be selected on a location-by-location basis to minimize the total communication cost.

Within the two classes, design flexibility is provided to minimize terminal cost, also on a location-by-location basis. DTU terminals in urban areas may be mechanized with smaller apertures and more expensive transmitters and receiver preamplifiers to reduce site requirements. The advantages include smaller wind loads for roof-mounted structures, less visual impact, and less use of valuable space. In rural areas, larger apertures may allow using less expensive transmitters and receiver preamplifiers for the same overall EIRP and G/T performance. Similarly, Gulf Coast users will have to use large apertures and more expensive transmitters and receiver preamplifiers, as compared to Western users, because of the larger rain-loss effects.

DTU terminal design complexity is minimized by using a standard DS1 interface, as used in the Bell System T1 digital carrier system for up to 24-voice channels of traffic. Special video interfaces will be required for video users, other than slow-scan video users who can operate within the 1.536-Mbps-effective DS1 data rate. Using a standard interface will allow commercially available, high-volume hardware up to the terminal interface.

The entire DS1 signal will not be transmitted through the satellite system, however. Synchronization pulses will be stripped out, unassigned channel data will be detected and deleted, and only the 64 kbps per active voice channel data will be transmitted. On the receive side, 64-kbps channel data from multiple sources will be assembled into a standard DS1 output signal with locally generated synchronization pulses. Automatic demand assignment will provide new channel connections within as required, giving a DTU terminal 24 effective full-time channels for each DS1 interface. Routing is accomplished on the satellite on a per-voice channel basis, so the voice channels coming into a DTU terminal on a particular DS1 interface may be routed to any number of destinations.

Several of the features of the DTU terminal were selected to standardize hardware designs and reduce terminal cost. DS1 signal buffering and automatic demand assignment features, described above, are examples. The DTU terminal design philosophy is to utilize command and telemetry data over a system order wire to provide the more complex functions in the system master control station. Local "intelligence" will be used in each terminal to keep each terminal's order-wire command and telemetry requirements below 1 kbps, or one bit per frame.

The DTU terminal synchronization subsystem uses calculator technology to calculate precise and accurate time advance for the terminal transmit signal (Figure 0-6). The calculation rate is very slow: 1 per 5 seconds. The calculated data drives a simple indirect synthesizer which deletes pulses from the receive time/frequency reference signal to provide the transmit time/frequency reference signal. Calculations are based on order wire "command" data, station location data, and station timing-bias calibration data. The result is a precise open-loop terminal synchronization technique that makes initial synchronization and net entry trivial. The cost should be less than burst-acquistion synchronization techniques since all circuit parameters are noncritical.

Minimization of terminal cost, primarily for the DTU terminals is a major decision factor in all design decisions. DTU terminal cost must be below $100,000 (1979 dollars) for an economic system design. A cost goal of $30,000 would, if met, make the system extremely competitive with terrestrial communication techniques. Table 0-5 describes a first cut at terminal costing. Further work is needed in integrating components and in assessing "learning-curve" factors in volume production.

C. Small Trunking Terminals

Small trunking terminals are mechanized using the same hardware as for DTU terminals, except that they require two terminal locations separated by about 10 km to provide space diversity. Trunking terminals require an availability of 99.99 percent to meet commercial trunking standards. In most parts of the country rain losses will drive availability below the "four nines" level with any reasonable degree of rain margin.

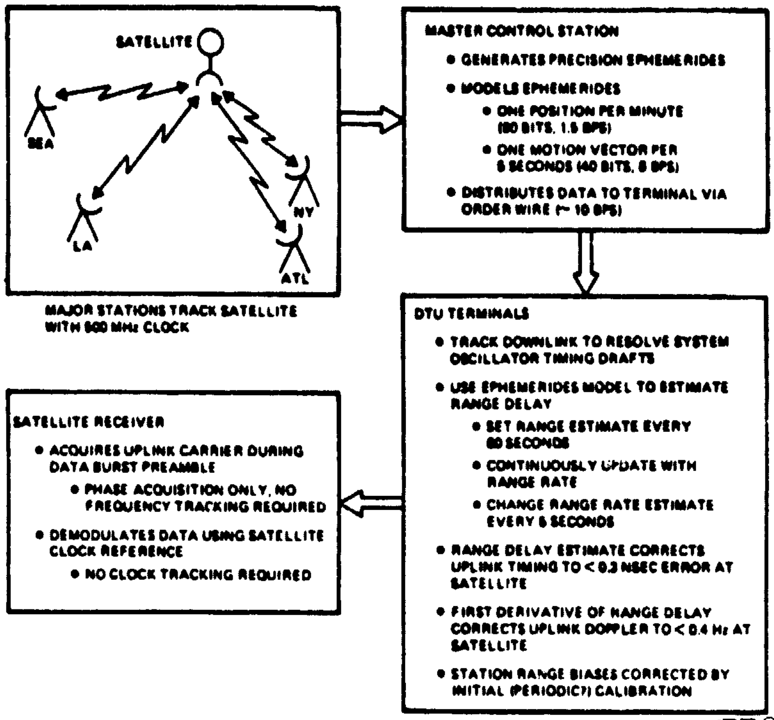

Figure 0-6. Terminal Timing Control

Table 0-5. DTU Terminal Cost Projections Summary

	Rack Space (inches)	Small Quantity Cost ($)	Total (%)	Development Cost ($)	Large Quantity Estimate ($)	(%)
Rack Mounted Modules						
Power Supply	12	7K	2.4		5K	3.9
Time and Freq Control	8	25K	8.5		15K	11.7
Encoder Decoder	3	3K	1.0		2K	1.6
Modem	12	125K	42.7	2000K	35K	27.3
Fault Iso and Test	10	30K	10.2		20K	15.6
Receiver - IF	6	16K	5.5		10K	7.8
Exciter-up Conv	6	12K	4.1		8K	6.3
Power Amp (Solid Sta)	6	10K	3.4	1000K	5K	3.9
Other (Rack, Cables)	-	15K	5.1		5K	3.9
Subtotal	5'3"	$243K	72.9		$105K	72.0
Pedestal Mounted						
Diplexer		2.5K	0.9		1.5K	1.2
LNA		2.0K	0.7		1.5K	1.2
Antenna and Pedestal		15.5K	5.3		10.0K	7.8
Step Track		30.0K	10.2	200K	10.0K	7.8
Subtotal		$50K	17.1		$23K	18.0
Total		$293K			$128K	

A 10-km separation between diversity sites reduces the rain-margin requirement to reasonable levels. The rain storms that cause outages are intense and small. Large rain storms do not have the rain intensity necessary to cause outages, or have small high-rain-intensity cells embedded in them. This fortunate physical characteristic results in statistical "decorrelation" of outages and makes 99.99 percent availability achievable with site diversity.

Fiber-optic communications are used to connect the two diversity sites. Microwave links may also be used where right-of-way problems are severe. However, the microwave link design must consider the same rain-loss effects that preclude single-site satellite tracking communications. Repeaterless operation of fiber-optic links over 10 km paths should be feasible in the planned operational time frame for the 30/20 GHz system.

Normal diversity operation will consist of parallel reception at both sites with transmission from a designated primary site. Data output will be from the site indicating the highest SNR or signal quality. Reduction in the received signal level at the designated primary site will cause transmission to be shifted to the designated alternate terminal. Rain attenuation effects between 20 and 30 GHz are very highly correlated, especially at intense rain rates where drop-size variations are small. As a result, downlink quality provides an excellent indicator to control uplink diversity switching.

D. Large Trunking Terminals

The large trunking terminals may be relatively expensive without strongly affecting system cost. This results from the small number of large trunking terminals. A very few large terminals may have very high data throughputs, up to three or four 500 Mbps channels. Most will have a single 500 Mbps burst rate TDMA channel.

The terminal receivers will use fast-acquisition demodulators to derive synchronization on each received TDMA burst if IF switching is used for 500 Mbps SSTDMA in the operational system. Transmit synchronization will use return modes in the SSTDMA switch, or transmit synchronization data may be extracted by the master control station (which will be at one of the large terminals) and distributed by system order wire.

Large terminal synchronization will be similar to DTU terminal synchronization if demodulation and remodulation with digital SSTDMA switching is used in the satellite, with some satellite received-clock-error feedback to the master control station.

In addition to data transmission, the large trunking terminals will provide the raw data used to derive the satellite position. This is done by measuring time delay on the 500-MHz high-rate data clock. The clock timing information is collected at each large terminal and transmitted to the master control station by order wire.

E. Master Control Station

The master control station will be located at one of the large trunking terminals. At least one alternate control station will be provided at another large trunking terminal. The master control station controls the satellite and the individual terminals. Functions controlled include:

- Satellite On-board Processing
- Scanning-Antenna Phase Shifting
- SSTDMA Modes and Dwell Times
- TWTA Power Levels
- Satellite Attitude Control Bases
- Satellite Stationkeeping
- Satellite Redundancy
- Satellite Housekeeping, Telemetry, and Command
- Satellite Ephemerides Data Reduction
- Individual Terminal TDMA assignments
- Individual Data Channel Routing Control
- Individual Terminal Control and Maintenance Planning.

To accomplish all the required functions, the master control station will incorporate a large computing capability. The master control station cost can be significant, but overall system cost will be minimized by centralizing the system computing requirements and utilizing the inherent system communication capability to collect data and distribute results.

Since alternate master control station capability is required for reliability and availability, the optimum design may place identical master control station facilities at several large trunking terminals. Computational tasks may normally be distributed to achieve high hardware utilization. Failures requiring shifts of control capabilities can be handled by deferring low priority tasks (maintenance scheduling and parameter trend evaluation, for example), and redistributing high priority tasks.

F. 30/20 GHz System TDMA Architecture

The baseline TDMA architecture has, for the most part, been described in the process of describing the baseline system segments; the satellite terminals, and master control station. DTU users communicate at 25- or 125-Mbps uplink burst rate and receive at 250-Mbps downlink burst rate. Small trunking users transmit 125-Mbps uplink burst rate data and receive at 250-Mbps downlink data rate. Small trunking terminals are indistinguishable from large DTU terminals in the TDMA architecture hierarchy. The only difference is site diversity which is required at most small trunking terminals to achieve 99.99 percent availability.

Large trunking users transmit and receive at 500 Mbps burst rate on both uplink and downlink. Their TDMA architecture is a straightforward SSTDMA, except for the sharing of their uplink and downlink channels by the DTU users (Figure 0-4).

The master control station philosophy provides efficient control of the instantaneous system TDMA architecture within the design limits. An example of the adaptive nature of this approach is provided by Figure 0-7, the time line for establishing a new voice.

Establishing new 64-kbps, voice-quality channels within the 1.35 seconds shown will require TDMA timing changes that could, theoretically, affect timing of all stations in the network. This level of impact will be avoided by appropriate distribution of system unused capacity throughout the areas being served. This time line illustrates the flexible behavior possible with a large disciplined system under centralized control.

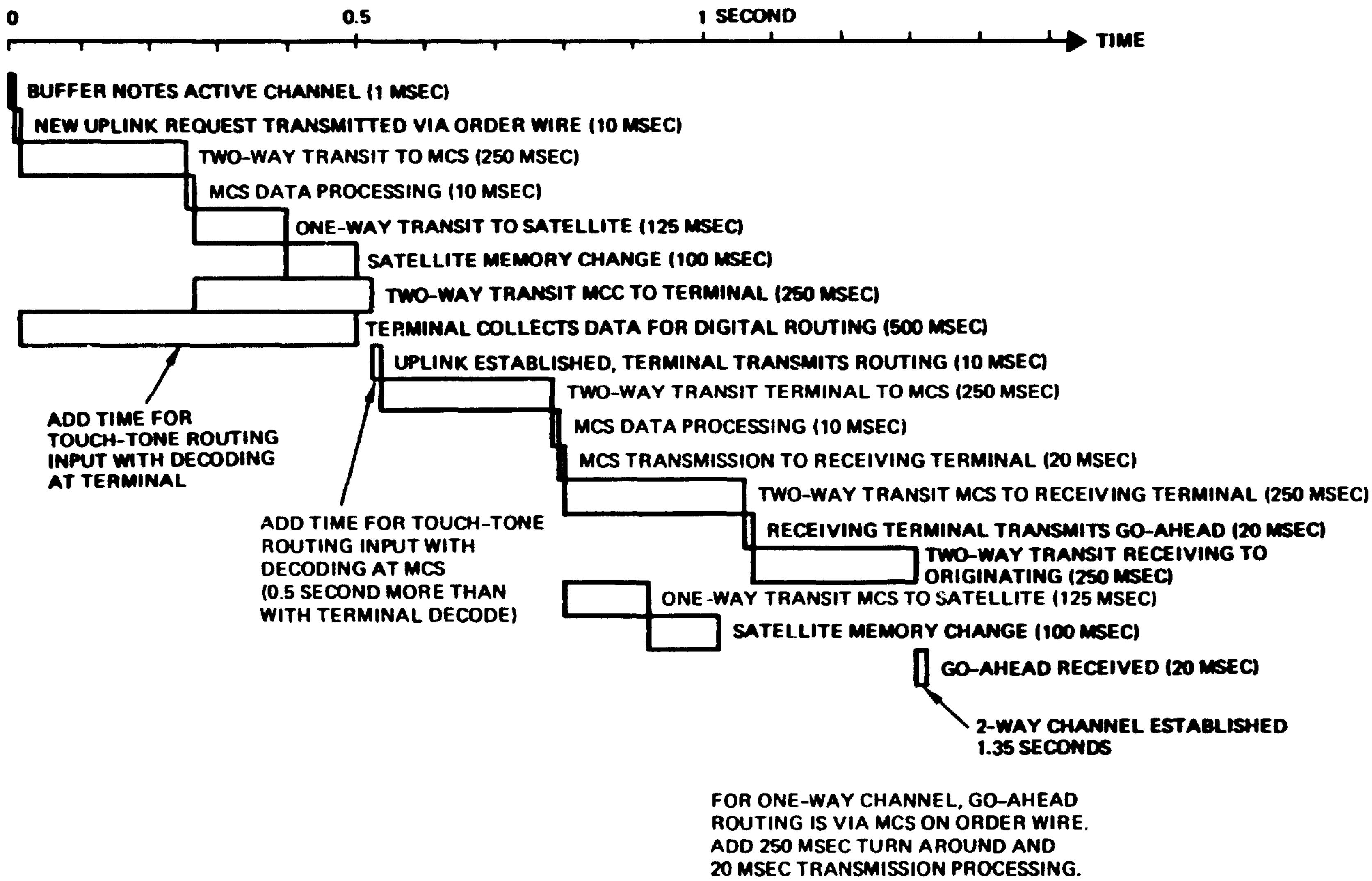

Figure 0-7. New Voice Channel Establishing Time Line